Project of Accelerator Complex for Extreme Ultraviolet Nanolithography Based on a Free Electron Laser

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Project activities:

The project is aimed at construction of accelerator complex, based on a 0.7 GeV superconducting linear accelerator, for applications in nanoindustry, mainly for EUV lithography using kW-scale Free Electron Laser (FEL) light source.

Project aims:

Construction of a 0.7 GeV superconducting linear accelerator to produce coherent FEL radiation for EUV nanolithography at a wavelength of 13.5 nm and an average radiation power of 0.5 kW.

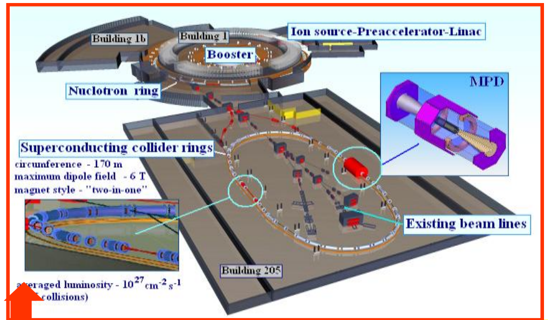
Development of a dedicated channel for extreme ultraviolet lithography with a few nanoscanners operating simultaneously in a processing line with 22 nm, 16 nm and beyond using FEL radiation at a wavelength 13.5 nm.

Medico-biological investigations using radiation with wavelengths ranging from 2.4 nm to 4.6 nm (3rd harmonic FEL) .

Research in magnetic materials using radiation with a wavelength of about 1.5 nm (5rd harmonic FEL).

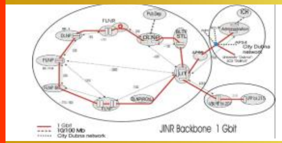
Realization of the superconducting RF linear accelerator technology for the International Linear Collider

Upgrade of JINR Basic Facilities

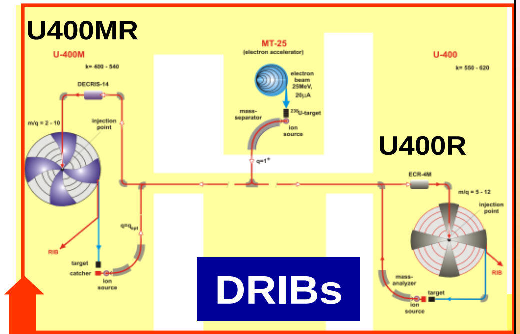


Upgraded Nuclotron-M
(2009 – 2010)
+
NICA (2013-2014)

Telecommunication channels:
20 Gbps – 2009
40 Gbps – 2010
720 Gbps – 2016



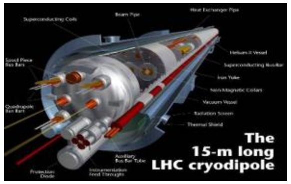
JINR networks:
- GRID technology
- improvement of computer links with Member States (2010-2016)



DRIBs II – (2009-2010)
DRIBs III – (2011-2015)

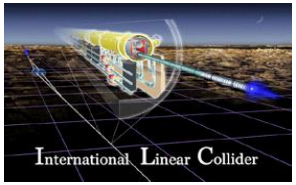
New reactor IBR-2M – 2010
Complex of modern neutron spectrometers (2011-2016)

Participating in LHC, RHIC, TEVATRON…
In future: FAIR, ILC …

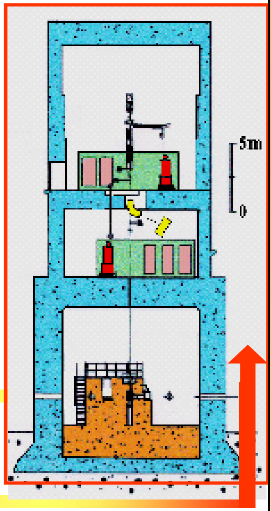


LHC-2008

FAIR-2015

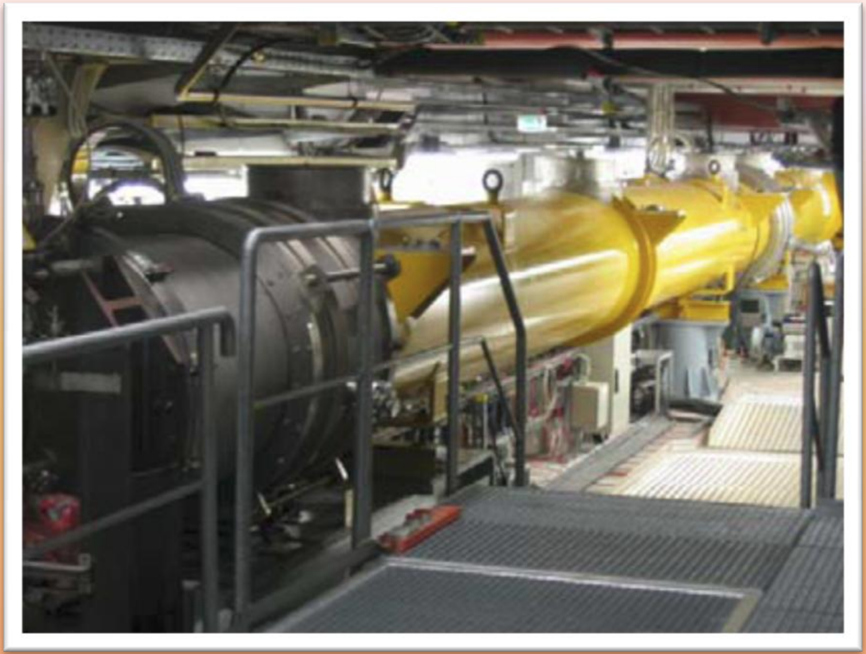


ILC – after 2020 (?)



IREN-I
2008

Accelerator complex for EUVL on basis of Free Electron Laser



FLASH (DESY, Hamburg) Linear superconducting accelerator is an analog of JINR accelerator for EUVL

FLASH undulator applied for generation of EUV coherent radiation

Electron beam at power of 100 kW is an active ambience in FLASH.

Russian input in XFEL Project (DESY, Hamburg) is 300 Mln. Euro

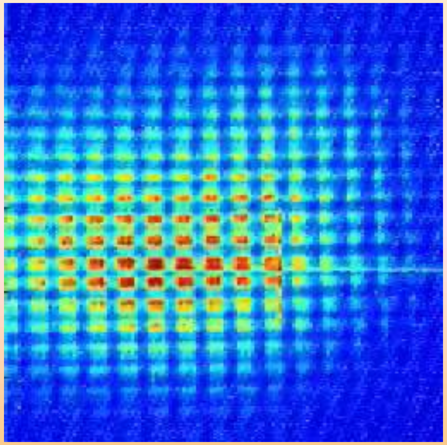
FLASH INFRARED UNDULATOR CONSTRACTED IN JINR

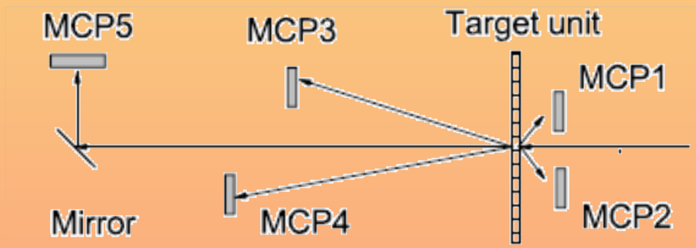
2006, JINR Workshop

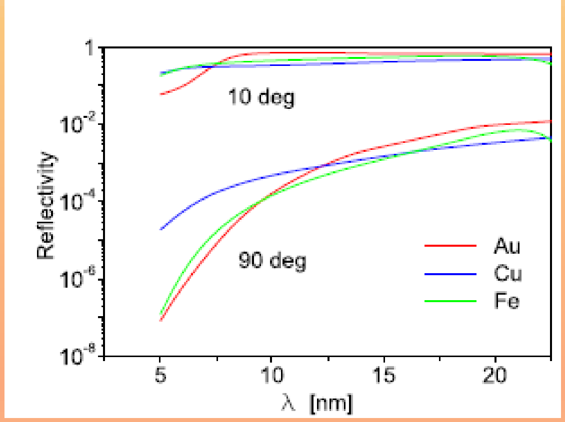
June 2007, DESY, FLASH, Hamburg

MCP Detector

Wave length	6-13 nm
Average pulse radiation	40 μJ
Duration of pulse of radiation	30 fs
Peak radiation power	5 GW
Relative spectral width (FWHM)	0.7%
Angular divergence (FWHM)	90 μrad
Peak Brilliance	~ 610^{29} ph/s/mrad^2/mm^2/(0.1%bw)

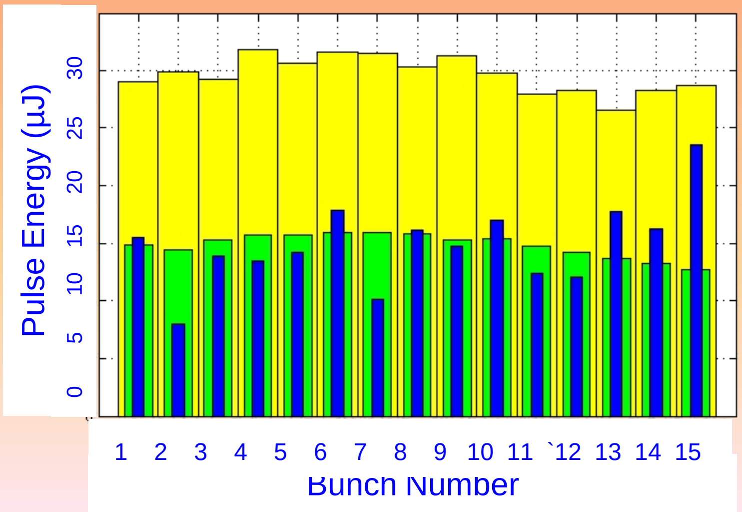




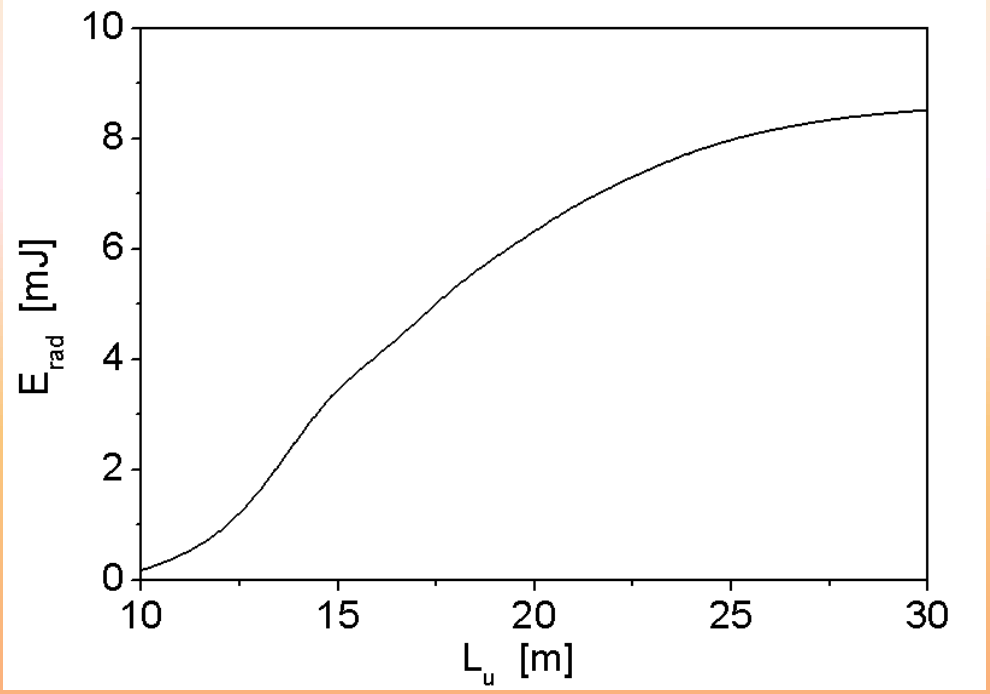


Cu and Fe wire grid is used for scattering of FEL radiation

MCP detector: JINR, Dubna



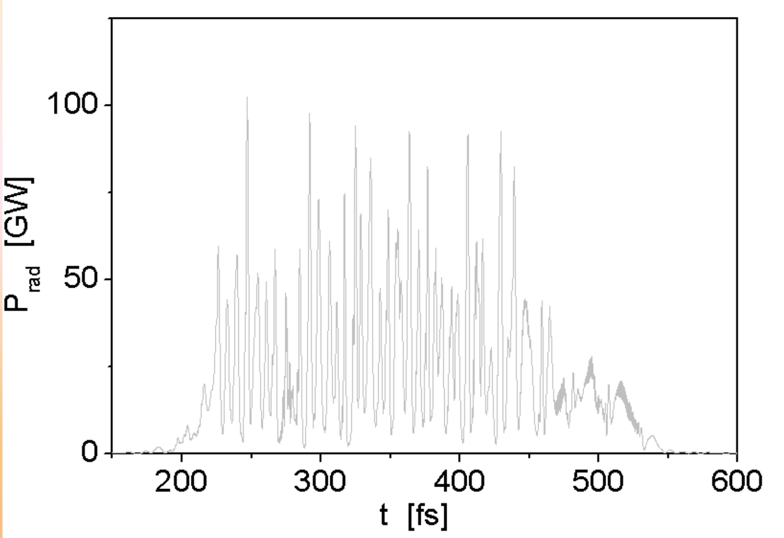
Micropulse radiation energy:



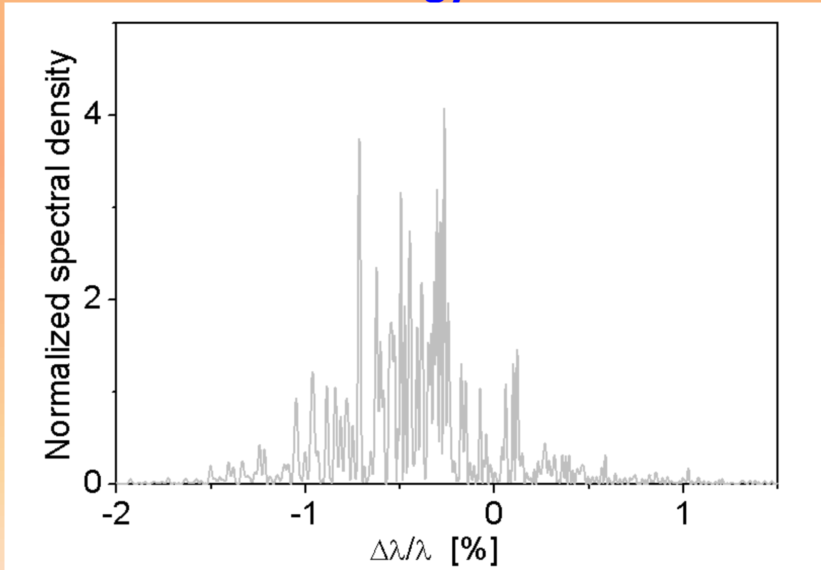
Dependence of FEL micropulse radiation energy on undulator length at electron energies E_e=680 MeV.

Micropulse radiation energy is equal to 8,5 mJ at E=680 MeV

Characteristics of FEL radiation

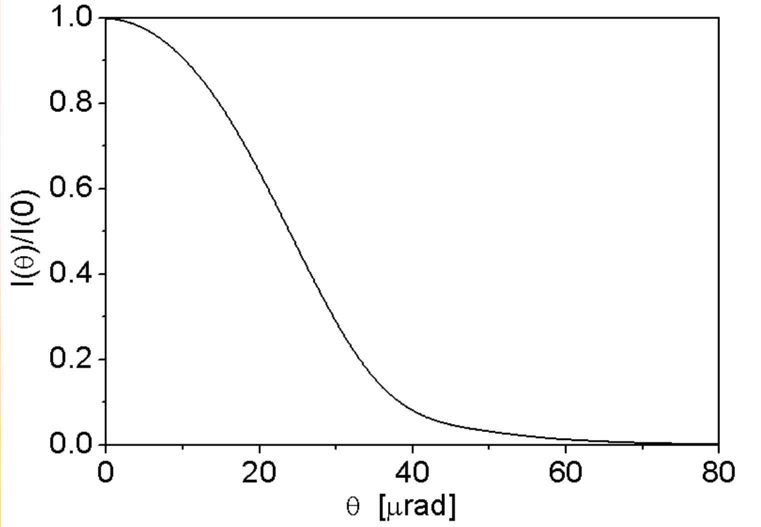


Dependence of pulse radiation power at wave length of 13,5 nm on time at electron energy of 0.68 GeV.

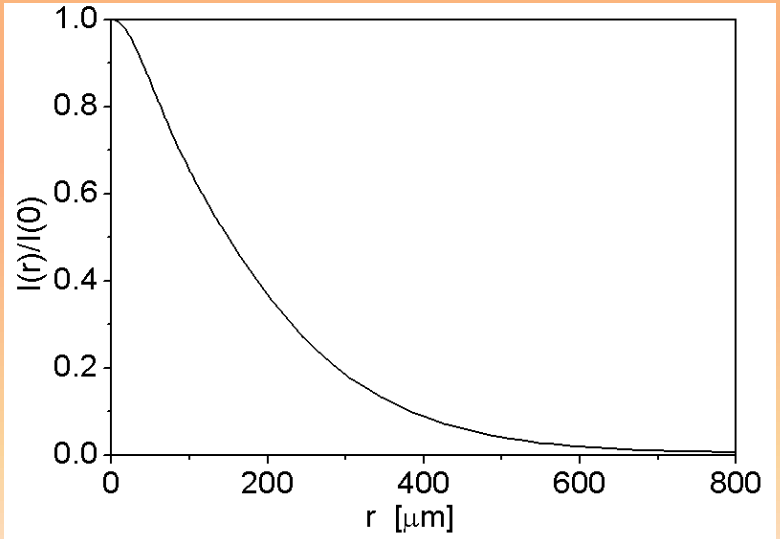


Spectral density of radiation at wave length 13,5 nm and electron energy of 0.68 GeV.

Characteristics of FEL radiation



Angle distribution in far field at wave length of 13,5 nm and electron energy 0,68 GeV.

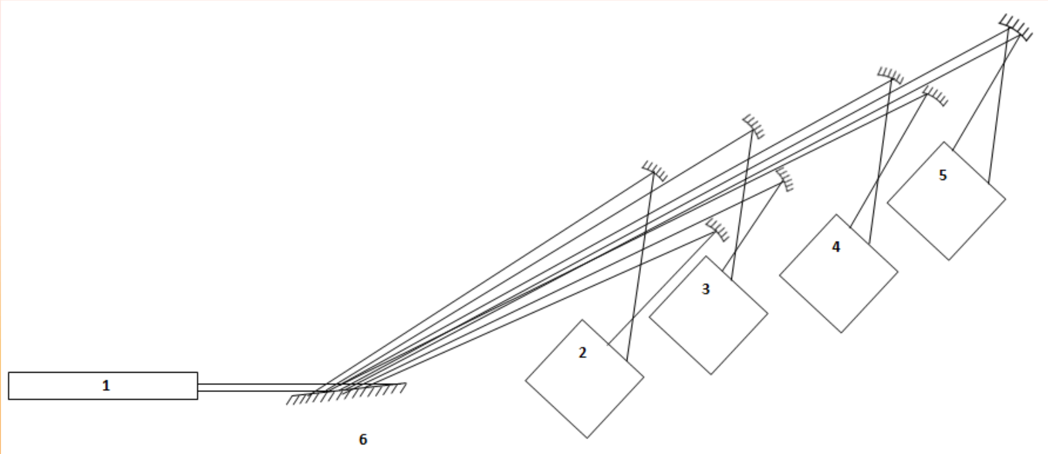


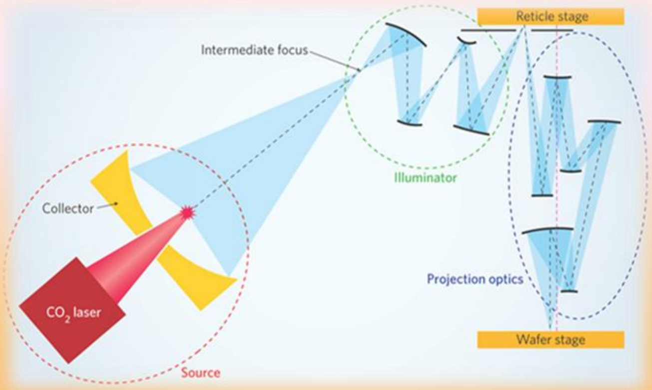
Intensity distribution in neighbor field at λ=13,5 nm and electron energy 0,68 GeV.

Parameters of accelerator complexes FLASH and FEL-EUVL

Ускорительный комплекс	FLASH	FEL-EUVL 1,25 GeV	FEL-EUVL 0,68 GeV
Electron energy, GeV	0.68 (1)	1.25	0,68
FEL lenght	250	180	110
Peak beam current, кA	2.5		
Macropulse frequency, Hz	10	10	40
Macropulse time duration, ms	0.8	0.8	0.14
Number of pulses per macropulse	7200	8000	1400
Micropulse frequency, MHz	9	10	10
Undulator lenght, m	27	30	30
Wave lenght, nm	13.5		
Specter width of radiation, %	2		
Micropulse radiation energy, mJ	1.4	22	8,5
Peak radiation power, GW	5.6	88	34
Macropulse radiation energy, J	10	176	12
Micropulse radiation time, fs	250		
Diameter of radiation spot at undulator exit, mm	0.17	0.2	0,3
Angle spread of radiation, μrad	30	54	48
Average radiation power, kW		1.76	0,48
Number of scanners		10	8

SCHEME OF FEL ACCELERATOR COMPLEX FOR EXTREME ULTRAVIOLET LITHOGRAPHY





Distribution of FEL radiation between lithography scaners, 1-FEL, 2-5 – lithography scanners, 6 – first mirror.

The FEL radiation is divided on the 8 simultaneously operated scanners. The FEL spot after defocusing mirror has a diameter of 50 cm which is divided on 8 concentric rings of equaled square by a special multilayer mirror system.
The radiation from each concentric ring is pick-upped by the corresponding scanner.
In each scanner a system consisted of 4 multilayer mirrors transforms the radiation ring in a bend with a size of 26×2 mm, which is exposited on chip by the 6 multilayer mirror objectives.

Comparison of FEL and LPP parameters

Parameter	LPP Cymer NXE:3100	JINR-FEL 1,25 GeV	JINR-FEL 0,68 GeV
Wave lenght, nm	13,5		
Micropulse radiation energy, mJ	2	22	8,5
Micropulse Frequency, kHz	50	10 000	10000
Number of micropulses	20 000	8000	1400
Macropulse time duration, ms	400	0,8	0,14
Macropulse frequency, Hz	2	10	40
Macropulse radiation energy, J	40	176	12
Average exposition power, W	100	1760	480

TIME STRUCTURE OF FEL AND LPP RADIATION

Parameter	LPP Cymer NXE:3100	JINR-FEL 1,25 GeV	JINR-FEL 0,68 GeV
Number of multilayer elements	11		
Coefficient of reflection	0,62		
Efficiency of radiation transmission to wafer	0,5%		
Micropulse radiation energy, mJ	2	22 (10 steppers)	8,5 (8 scanners)
Density of radiation energy mJ/cm^2	10		
Energy of chip line (2.6×0,2 cm^2) exposition, mJ	5,2		
Energy of chip exposition (2.6×3.2 cm^2) mJ	83		
Energy of wafer exposition (300 mm), J	6		
Scanning speed, mm/ms	0,2	Stepper	0.1
Average exposition power of radiation source, W	100	1760 (10 steppers)	480 (8 scanners)
Average power of wafer exposition, W	0,5	0,9	0,3
Number of micropulses for exposition of chip line	520	470	1250
Time of chip line exposition, ms	10	0,047	0.125
Number of micropulses for chip exposition	8300	7520	20 000
Time of chip exposition, ms	160	100	320
Number of macropulses for wafer exposition. Time of wafer exposition, s	28 14	70 7	1120 22.5
Time of wafer exposition and its replacement, s	36	29	44
Production wafer rate w/h	100	1250 (10 steppers)	640 (8 scanners)

JINR base for project realization

JINR base and production potential :

•JINR has experience of production of large scale acceleration complexes.

• JINR realized in present time Project IREN for neutron reactor IBR-2 on basis linear accelerator.

•JINR has infrastructure for EUVL Project (buildings at length of 200 m with radiation protection, required power consumption, cryogenic systems and so)

•EUVL Project in JINR is oriented on realization of International Linear Collider (JINR is considered as a possible host) at length of 30 km.

Experience:

• JINR experts are involved in creation of acceleration technique.

• JINR experts take participation in Europe FEL Projects FLASH and XFEL (DESY, Hamburg).

• JINR constructed superconducting synchrotron- Nuclotron and has cryogenic infrastructure and experts for realization of EUVL Project.